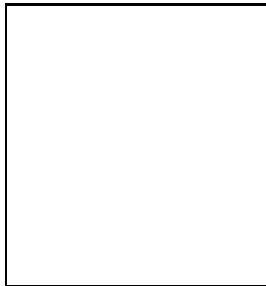# Searches for New Physics at DØ

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The integrated luminosity at Run 2 of the Tevatron is approaching the Run 1 total, and data analysis is progressing. New results in searches for new physics by the DØ experiment are presented in a variety of channels, demonstrating good performance of the detector and detailed understanding of the data.

1 Introduction

The DØ experiment has been taking data at Run 2 of the Tevatron since March 2001. In the early part of the run, the data was used for detector commissioning and calibration, and only data taken since April 2002, when the fiber tracker instrumentation was completed, is used for physics analysis. Between April 2002 and January 2003, the Tevatron delivered 135 pb^{-1} of integrated luminosity, of which 83 pb^{-1} were recorded by DØ. It should be noted that DØ's datataking efficiency increased gradually during this period, and reached 90% at the end of 2002. The results presented here use up to 50 pb^{-1} from that data sample.

2 Searches for Supersymmetry

Signals for supersymmetry are searched for in a variety of signatures predicted by various models of supersymmetry breaking. A few of these are presented here. For a given superpartner mass, production cross-sections at the Tevatron are highest for colored particles and lowest for particles that only interact weakly. However, while the cross-sections are therefore highest for squarks and gluinos, these are expected to be significantly heavier than the electroweak gauginos, such that for a given point in parameter space the production rates are similar [1].
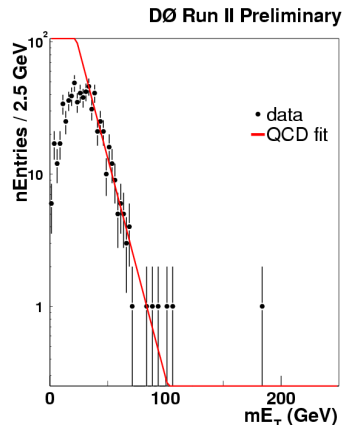
DØ Run II Preliminary

Figure 1: Distribution of jets + missing E_T events as a function of missing E_T. The data (points) is fitted (line) at moderate missing E_T to estimate the QCD contribution to the high missing E_T region.

Table 1: Expected and observed events for various cuts on the minimal event missing E_T. The last line gives a limit on the new physics production cross-section of events with at least two hard jets (of which one has $p_T > 100 \ GeV$) and large missing E_T.

Cut: Missing $E_T >$	70 GeV	80 GeV	90 GeV	100 GeV
Expected Events	18.4 ± 8.4	9.5 ± 5.3	5.1 ± 3.2	2.7 ± 1.8
Observed Events	7	6	4	3
95% C.L. Cross-Section Limit (pb)	4.2	3.8	3.1	2.7

2.1 Jets and Missing E_T

The generic signature for production of squarks and/or gluinos in SUGRA-type models consists of jets and missing transverse energy (missing E_T). These come from the cascade decays of the squarks and gluinos into quarks, gluons and the Lightest Supersymmetric Particle (LSP). In these models the latter is heavy ($\mathcal{O}(100 \ GeV)$), neutral, stable and weakly interacting, such that it escapes the detector undetected, leaving as its only signature an imbalance in transverse momentum.

This type of signature unfortunately suffers from very significant instrumental backgrounds, due to the tails of the dominant standard model production of jets (denoted QCD in the following). A pilot analysis has been performed using 4 pb^{-1} of data in order to demonstrate that these backgrounds could be understood and reduced sufficiently. The analysis starts by applying a series of "cleaning" cuts designed to reduce the instrumental background, followed by topological cuts to increase the signal over background ratio. After that, the physics backgrounds are evaluated using simulation, and the QCD background is derived from the data at moderate missing E_T. This is illustrated in Figure 1. As can be seen from Table 1, the number of data events at high missing E_T is in good agreement with the expectations and does not exhibit any anomalous tails.

2.2 Di- and Trileptons

The cascade decays of the electroweak gauginos, which are predicted to be relatively light, often lead to signatures with multiple leptons. At hadron colliders, this is the SUGRA channel with the lowest background, and is often called the "golden channel". It should be noted however that good sensitivity to this signal requires both low lepton p_T thresholds (because of the small
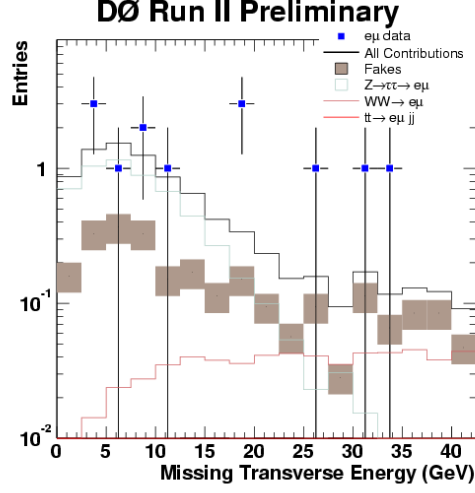
Figure 2: Distribution of expected (histogram) and observed (points) $e\mu$ events as a function of missing E_T.
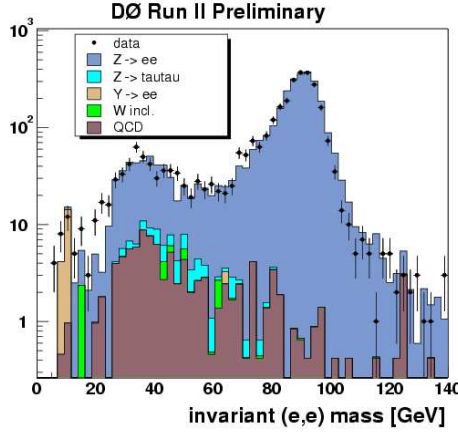

Figure 3: Distribution of expected (histogram) and observed (points) ee events as a function of dielectron invariant mass.

mass difference between the gauginos and the LSP), and the ability to identify hadronic tau decays. This is due to the fact that at large $\tan\beta$ the leptonic branching fractions for charginos and neutralinos are dominated by taus.

Among the multilepton signatures, the channel with an electron and a muon has such low backgrounds that the analysis is pursued in a model-independent way. Events are required to have at least one electron and one muon, both with $p_T > 15\ GeV$. The fake rates are estimated from data, while the physics backgrounds are evaluated from simulation. The dominant physics backgrounds are $Z \to \tau\tau$ at low missing E_T, and WW and $t\bar{t}$ production at high missing E_T. In approximately 30 pb^{-1} of data (the uncertainty on the luminosity is currently conservatively estimated at 10%), the data agree well with the backgrounds as can be seen from Figure 2. Based on this, a model-independent upper limit on acceptance $\times$ cross-section is set for new physics leading to events with an electron and a muon as a function of missing E_T. This limit ranges from about 400 to 100 fb for missing E_T going from 0 to 35 GeV.

The study of channels with two electrons and a third lepton starts with the study of the dielectron invariant mass spectrum. This is shown in Figure 3 and is used to check that trigger, reconstruction, simulation and the QCD fake background are well understood. While not perfect

Table 2: Expected and observed events for successive cuts on dielectron events.

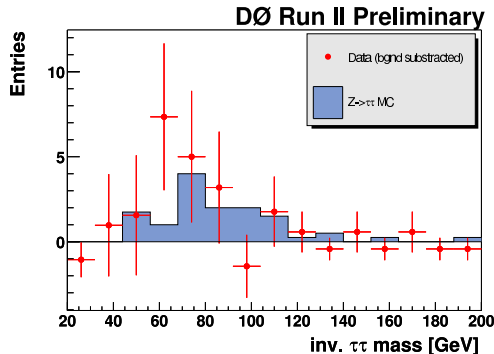|	Backgrounds	Data
$p_T(e_1) > 15\ GeV, p_T(e_2) > 10\ GeV$	3216 ± 43.2	3132
$10\ GeV < M_{ee} < 70\ GeV$	660.2 ± 19.1	721
$M_T > 15\ GeV$	96.4 ± 8.1	123
Additional Isolated Track, $p_T > 5\ GeV$	3.2 ± 2.3	3
Missing $E_T > 15\ GeV$	0.0 ± 2.0	0

Figure 4: Distribution of candidate $Z \to \tau\tau X \to ehX$ events (points) as a function of reconstructed ditau invariant mass. Also shown is the expectation from simulation (histogram).

yet, the agreement is good. This analysis uses approximately $40\ pb^{-1}$ of data, and the successive cuts, along with the expected and observed numbers of events are given in Table 2. The typical selection efficiency for SUGRA events at points in parameter space close to the current exclusion limit is 2-4%, but the sensitivity is still about a factor of 7 away from extending the excluded area. In addition to increased integrated luminosity, efforts are underway to improve the sensitivity by improving the efficiencies and adding other channels.

One of these approaches involves identifying $Z \to \tau\tau$ events where one of the taus decays hadronically. For the $p\bar{p} \to ZX \to \tau\tau X \to ehX$ channel, events with an electron with $p_T > 12\ GeV$ and a tau-like jet are selected from about $50\ pb^{-1}$ of data. The tau-like requirements are a cut on the jet width, and only one track with $p_T > 1.5\ GeV$ compatible with the tau mass (i.e. starting from the leading track, the two-track invariant mass is calculated for all tracks with $p_T > 1.5\ GeV$ and required to be below the tau mass). For each of the tau decay channels (with or without a neutral pion), a neural net using both calorimetric and tracking variables for inputs is used to discriminate between QCD and tau jets. After cutting on the neural net outputs, the ditau invariant mass is reconstructed under the hypothesis that the tau direction is the same as the visible tau daughter direction. Finally, same-sign $e\tau$ events are subtracted from opposite sign events, leading to the histogram shown in Figure 4, indicating a clear signal which can be used to further improve the identification of hadronically decaying taus.

2.3 Diphotons and Missing E_T

As opposed to the SUGRA scenario, in Gauge Mediated Supersymmetry Breaking (GMSB) the LSP is a very light ($\ll eV$) gravitino, and the model phenomenology is driven by the nature of the NLSP (Next-to-Lightest Supersymmetric Particle). In the case of a "bino-like" NLSP, events will have 2 energetic photons and large missing E_T. This search uses about $50\ pb^{-1}$ of data, requires two photons with $p_T > 20\ GeV$, and applies quality and topological cuts to reduce the instrumental backgrounds and increase the signal over background ratio. The remaining
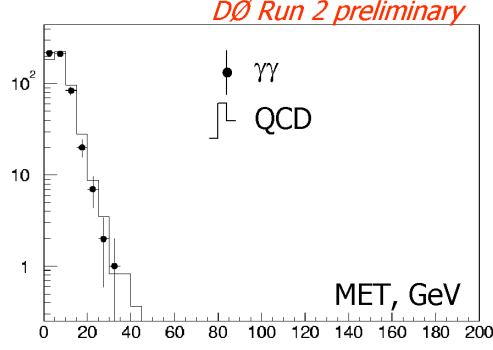
Figure 5: Distribution of diphoton events (points) as a function of missing E_T. The histogram is the expected background from QCD fakes.
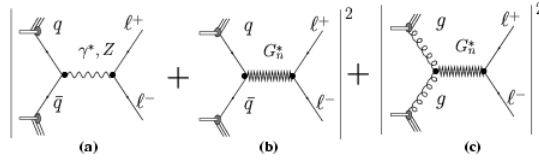

Figure 6: Feynman diagrams showing contributions of virtual graviton exchange to Drell-Yan processes.

background is dominated by QCD fakes and is determined from data. The resulting missing E_T distribution is shown in Figure 5 and shows good agreement between data and backgrounds. A limit is set on GMSB using the Snowmass slope [2] with Λ as the only free parameter and $M = 2\Lambda, N_5 = 1, tan\beta = 15$ and $\mu > 0$. The limit corresponds to a lower limit on the neutralino mass of 66 GeV at 95% C.L., very close to the Run 1 result.

3   Exotics

One of the more exotic signals for new physics DØ searches for is leptoquarks. The analysis presented here uses about 30 pb^{-1} of data to search for second generation leptoquarks decaying to a muon and a c or s quark. Events are required to have two opposite sign muons with $p_T > 15$ GeV, two jets with $p_T > 20$ GeV and $M_{\mu\mu} > 110$ GeV. The dominant background comes from $\gamma^*/Z \to \mu\mu + jets$, and since no events are found a lower limit on the leptoquark mass is set at 157 GeV, 43 GeV worse than the Run 1 limit.

4   Large Extra Dimensions

DØ searches for Large Extra Dimensions (LED) in the ADD [3] model assuming standard model particles are confined to a 3-brane, but gravity propagates in the extra dimensions. In these analyses, the signature is an excess of high-mass dielectron, diphoton or dimuon events due to the coupling to Kaluza-Klein gravitons. Figure 6 shows Feynman diagrams of the standard model and graviton contributions to the dilepton processes, which can be parametrized as follows:

$$\frac{d^2\sigma}{dM d\cos\theta^*} = f_{SM} + f_{interf}\eta_G + f_{KK}\eta_G^2. \tag{1}$$

Here $\cos\theta^*$ is the scattering angle in the di-em or dimuon rest frame, and η_G measures the contribution from gravitons. The dielectron and diphoton channels are treated simultaneously (I.e. no track requirement is imposed) so that events are required to have 2 electromagnetic objects with $p_T > 25$ GeV, and missing $E_T < 25$ GeV to ensure the events are well measured.
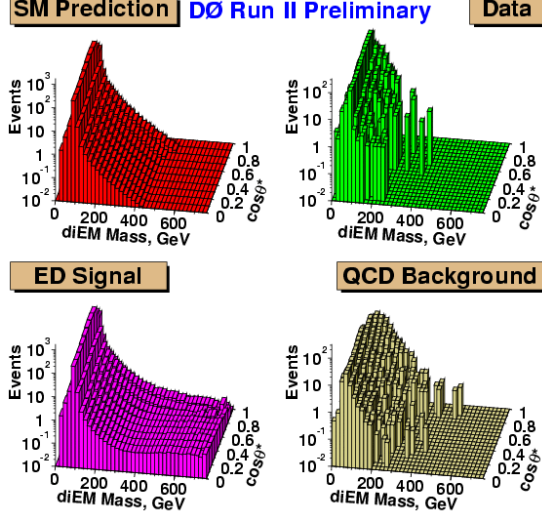
Figure 7: Standard model expectation, data, extra dimension signal and QCD fake background in the invariant mass - $cos\theta^*$ plane for the di-em channel.

Table 3: Lower limits in TeV on M_S, the fundamental Planck scale, for various formalisms (see text).

Formalism	GRW	HLZ, n=2	HLZ, n=7	Hewett, $\lambda = +1$
Di-Em ($\approx 50pb^{-1}$)	1.12	1.16	0.89	1
Dimuon ($\approx 30pb^{-1}$)	0.79	0.68	0.63	0.71

In the dimuon channel, two muons with $p_T > 15\ GeV$ and $M_{\mu\mu} > 40\ GeV$ are required. In both cases, physics backgrounds are derived from simulation and instrumental backgrounds from data. The data distribution in the invariant mass - $\cos\theta^*$ plane is then fitted to signal + background (see Figure 7) to evaluate an upper limit on η_G. This limit is translated into a lower limit on M_S, the fundamental Planck scale, with results shown in Table 3 for various formalisms [4]. The dielectron and diphoton channel yields a limit which is very close to the Run 1 result, while the dimuon channel is new at hadron colliders. Both results are competitive with LEP.

5   Conclusions

DØ continues to search for many different signatures for new physics. The effects of increased center-of-mass energy and an improved detector can now be seen in improved sensitivity compared to Run 1, and efforts continue on calibration and reconstruction to further extend the experiment's reach. We are now entering uncharted territory, so signal could be just around the corner.

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2. P3 Summary Report, Proceedings of Snowmass 2001, Ed. N. Graf.
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4. G. Giudice et al., Nucl. Phys. **B544**, 3 (1999); T. Han et al., Phys. Rev. D **59**, 105006 (1999); J. Hewett, Phys. Rev. Lett. **82**, 4765 (1999).